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A DIFFERENTIAL INFLUENCE OF AUGMENTED FEEDBACK ON LEARNING AND ON PERFORMANCE

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(Prepared under Contract No. AF 33(616)-6964
by
Robert G. Kinkade
Laboratory of Aviation Psychology
The Ohio State University
Columbus, Ohio)

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FOREWORD

This study was initiated by the Behavioral Sciences Laboratory of the 6570th Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio. The research was conducted by the Laboratory of Aviation Psychology, The Ohio State University Research Center, 1314 Kinnear Road, Columbus 12, Ohio. Dr. George E. Briggs, Director of the Laboratory was Principal Investigator. Dr. Marty R. Rockway, Chief of the Operator Training Section, Training Psychology Branch, Behavioral Sciences Laboratory was the contract monitor for the 6570th Aerospace Medical Research Laboratories. The work was performed in support of Project No. 7183, "Psychological Research on Human Performance," Task No. 718306, "Research on Human Learning and Related Methodology." The research sponsored by this contract was started in December 1959 and was completed in October 1961.

The author acknowledges the encouragement and support of Dr. Briggs. This research formed a part of the author's doctoral dissertation which is on file at the Ohio State University Library.

ABSTRACT

A test was conducted of the hypothesis that the training value of augmented feedback in a tracking situation will depend upon the discernibility of input and fundamental feedback signals. Subjects performed a one-dimensional compensatory tracking task using a knob for positional control over the cursor. For two of four groups of subjects the reference element was noisy, oscillating at random about a null position, while for the other two it was not. Augmented feedback, in the form of auditory clicks at the rate of 2 per second when on target, was given one of each pair of groups during training. On subsequent tests the performance of the group trained with augmented feedback and performing with the noisy display deteriorated to the level of its control group trained without feedback. But, the performance of the group trained with augmented feedback and performing on the noise-free display continued unchanged and superior to that of its control group trained without feedback. The results are regarded as confirming the hypothesis and as helping to explain previous contradictory findings on the value of augmented feedback.

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.

Walter F. Grether

WALTER F. GRETHER
Technical Director
Behavioral Sciences Laboratory

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INTRODUCTION

As the term implies, augmented feedback is supplementary information to some fundamental signals which are fed back to the human operator in a skill task. In their taxonomy, Annett and Kay (ref. 1) list two classes of information feedback signals: intrinsic and extrinsic. The first category represents signals intrinsic to or fundamental for the operation of a task itself. As an example one may cite the artificial horizon, the bank and turn indicator, the compass, the climb rate indicator, and the tachometer, which provide feedback information fundamental to the maintenance of attitude control of an aircraft under IFR conditions. Augmented feedback is an example of extrinsic feedback and is illustrated by such events as a mission critique by the squadron commander, the verbal comments of a check pilot, the comments of an evaluation team, etc. It is apparent that augmented feedback is not necessary for the successful operation of a system, but it is clear that the operation of a system can be improved by appropriate use of augmented feedback.

There are several basic differences between fundamental and augmented feedback. First, it should be noted that both forms of feedback are based on the same source of information: the behavior of a man-machine system in its operational environment. On the one hand, fundamental feedback is direct in the sense that the information is available with no artificial lag times. It is direct also in the sense that in most cases the data have not been subjected to transformations. A notable exception to this latter point occurs in the use of quickened or aided displays (ref. 5) and predictor instruments (ref. 10) wherein the basic feedback and/or system error signals (the raw data) have been subjected to derivative-like and extrapolation transformations, respectively, prior to display to the human operator. Augmented feedback, on the other hand, is information based on a sample of behavior taken over a span of time, and it is transformed information in the sense that the behavior of the man-machine system is subjected to a comparison with external criteria of proficiency. Thus, the signal actually fed back to the human operator represents an <u>evaluation</u> of performance based on these criteria. Both of these characteristics indicate that augmented feedback will occur after some lag time and that it is evaluative, not direct as in fundamental feedback, i.e., fundamental feedback is information displayed without comment whereas augmented feedback, by definition, is evaluative.

These points are summarized in Figure 1 where the augmented feedback loop contains the evaluation operation which, as shown, is achieved by comparing system input (what should be done) with system output (what actually was done) and evaluating the discrepancy against externally imposed criteria (how it should have been done). It may be noted that the training situation is replete with augmented feedback and that one of the primary functions of an instructor is the generation of such evaluative information. Thus, augmented feedback is a training variable of major interest, and the present research attempts to determine under what conditions augmented feedback will have a relatively permanent effect on proficiency of performance.

<u>Transfer Effects</u>

The majority of research on augmented feedback in a tracking task has shown that during training subjects (<u>S</u>s) provided with such information excel other <u>S</u>s

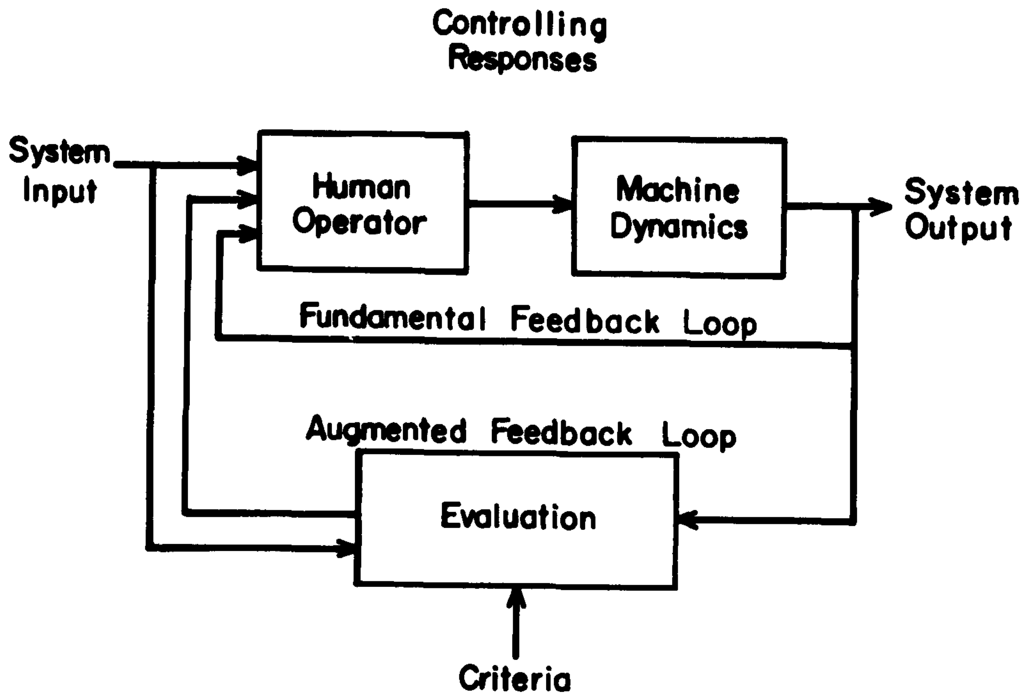

Figure 1. Simplified Man-Machine Paradigm to Illustrate Fundamental and Augmented Feedback Loops.

who perform the same task without the additional feedback cues. However, the literature is not consistent in finding continued superiority of augmented feedback groups when that additional information is withdrawn (upon transfer to a no-augmented-feedback condition). Bilodeau (ref. 4), Goldstein and Rittenhouse (ref. 8), Houston (ref. 9), and Underwood (ref. 15) all report performance deterioration following transfer to or near the level attained by control Ss who never experienced augmented feedback, while Kinkade (ref. 11), Minor (ref. 12), Reynolds and Adams (ref. 13), and Smode (ref. 14) found that augmented feedback groups continued to perform at a superior level following transfer.

An examination for a possible reason for this inconsistency reveals that the former studies all employed the Pedestal Sight Manipulation Task (PSMT) to define the tracking situation, while the latter studies employed either a standard rotary pursuit apparatus or the SETA apparatus (ref. 7) to define the skill task. Barthol (ref. 3) has observed that in the PSMT task, the display of the target on the viewing screen is fuzzy at best and that ranging cues, in particular, are not clearly perceptible. However, it is apparent in the case of the rotary pursuit and the SETA tasks that the input and fundamental feedback cues are clearly perceptible.

These observations led to the following hypothesis: in continuous control tasks which provide clearly discernible input and fundamental feedback signals,

augmented feedback cues are employed by S primarily as confirmation of adequate (or inadequate) controlling behavior. However, if the fundamental feedback information is obscured, S will utilize augmented feedback not as supplementary information but as a substitute for the fundamental feedback signals.

From this hypothesis one may make the following deduction: with clearly discernible input and fundamental feedback signals, augmented feedback is supplementary and therefore not an essential feature of the control task. Thus, deletion of augmented feedback following training should not result in performance deterioration. However, to the extent that S utilizes augmented feedback in place of obscured fundamental feedback cues, to that extent performance deterioration would be expected upon transfer to a no-augmented-feedback condition (as when transferring from training to operational environments).

The following experiment represents an evaluation of these predictions, and since they represent deductions from the above hypothesis, the study is, then, a test of that hypothesis.

METHOD

Apparatus

A one-dimensional, electronic, compensatory tracking instrument (SETA) was utilized in the experiment. The tracking display was provided by a 5-inch cathode-ray tube which contained two elements: two vertical lines which slightly overlapped each other when adjusted for zero error. The upper line served as the reference (or target) element while the lower line represented the cursor. The display was located approximately 18 inches in front of S at a 15-degree angle below S's horizontal line of sight. Positional control of the movement of the cursor was provided by a knob 1 inch in diameter, located below and to the right of the compensatory tracking display. A Gaussian noise generator enabled the E to introduce visual noise in the S's display by perturbing the reference element into random oscillations between 0.01 and 1.0 cps to an amplitude range of 0.75 inch around a null position. When used this visual noise appeared only in the reference element (target) and not in the movable cursor under S's control.

The waveform of the tracking input corresponded to a fundamental with a 6-cps frequency and a harmonic with a 12-cpm frequency; the amplitude ratio of these two components was 10:8. The tracking input can be specified as

$$E = 10 \sin wt + 8 \sin wt$$

where E is angular degrees of cursor deflection of the CRT display, w is 0.6283 radians/second, and t is the time in seconds. A constant-speed motor was used in a timing circuit which automatically started each trial at the same point on the input and stopped each problem at the end of 30 seconds. In order to eliminate the usual transients in tracking performance which occur at the beginning of each trial, the measurement of tracking error was initiated 5 seconds after the start of each trial.

Augmented feedback (auditory clicks) was presented to S through Wilson Sound Barrier earphones. Activation of the augmented feedback signal depended upon a

sensing device, which could be adjusted for any desired bandwidth. The sensing device operated a relay when the tracking error voltage fell within the tolerance level set by E. Operation of the relay closed the earphone circuit, thus providing auditory clicks at the rate of two per second as long as S remained "on target."

The primary measure of tracking performance was integrated absolute error. The tracking error voltage was fed into a conventional DC amplifier which translated error into absolute values which were then integrated by a second operational amplifier. This score will be identified as average error.

Subjects

Sixty volunteer, undergraduate, female students were paid for service in the experiment. Females were used as Ss principally because they are more naive concerning motor skills than males (ref. 2), and therefore they should produce better indications of trends during the initial acquisition of skill. The Ss were matched on the basis of their performance during eight initial trials. During these trials there was no visual noise imposed on the target and no augmented feedback was present. These Ss then were assigned to one of four groups, making a total of 15 Ss per group.

Experimental Procedure

There were two experimental and two control groups where the presence of augmented feedback defined the difference between experimental and control groups. One experimental and one control group experienced visual noise during each of 40 training trials, whereas the remaining two groups observed a noise-free display. Following the 40 training trials the augmented feedback signal was removed for the two experimental groups and 24 transfer trials were completed. The error tolerance for activation of augmented feedback was set at a bandwidth which was expected to produce the augmented feedback signal approximately 66% of the time during the initial trials when no noise was imposed on the target. Such a broad error tolerance was chosen so that the experimental group with visual noise imposed on the target would receive enough augmented feedback to be effective during the initial training trials.

Specifically, the four conditions employed in this study were as follows: group E_o—augmented feedback was present when S's tracking error was within the fixed error tolerance, and visual noise was not imposed on the target reference indicator; group C_o—augmented feedback was not present, and the target was noise-free; group E_n—augmented feedback was present when S's tracking error was within the fixed error tolerance, and visual noise was imposed on the target; and group C_n—augmented feedback was not present and the target was perturbed by the noise generator. During transfer both group E_n and group C_n continued to experience visual noise, of course.

The same initial instructions were read to each S, and she was informed that the control knob should be turned continuously in order to keep the cursor of the tracking display in coincidence with the target. The experimental group Ss were told further that clicks would be heard when the cursor was close to the target position, but that the auditory clicks indicated only minimal proficiency and that zero error on the display was the ultimate goal in the task. The latter

instructions concerning the clicks were omitted for Ss in the control groups who received no augmented feedback. Before each session, all Ss were reminded that the ultimate goal in the task was zero display error. In addition, Ss who were to track with visual noise imposed on the target were told to estimate the center or average of the perturbations of the target, and to keep the cursor on that estimated zero reference. After every two 30-second trials, the location of the null position on the display was changed to a new, randomly selected, position. This was done in order to prevent S from locating the target position with respect to some reference external to the visual display. The range of locations for the null position was ± 0.5 inch horizontally from the middle of the display.

Eight matching and 4 training trials were completed on the first day; 16 training trials were completed on each of the following two days; on the fourth day, 4 training and 12 transfer trials were completed; and, on the last day, 12 transfer trials were completed, making a total of 40 training and 24 transfer trials. Each trial lasted for 30 seconds with a 20-second rest interval between trials. The Ss were not given any quantitative indices of their performance until they completed the last session. At that time their performance data were shown and a complete statement was made of the purpose of the experiment.

RESULTS

The major comparisons are presented in Figure 2 where tracking proficiency, measured by the average error metric, is shown as a function of practice. Each point in the figure is the mean of four 30-second trials for each S averaged over the 15 Ss in each group, representing a total behavioral sample of 30 minutes of tracking. The average error score is the average deviation of S's error amplitude distribution; thus, the smaller the score, the more accurate the tracking performance.

Training

During the ten training blocks it is apparent that augmented feedback produced the usual superiority of performance (groups E_o and E_n versus groups C_o and C_n, respectively). It is apparent also, from Figure 2, that visual noise exerted a systematic effect on performance: groups E_n and C_n were inferior to groups E_o and C_o, the latter having experienced a noise-free tracking display. The latter result may be taken as a clear indication that visual noise was an effective means of obscuring the fundamental feedback cues.

An analysis of variance was performed on the data of all four groups over the final six blocks of training. The results of this analysis are provided in Table 1. It may be noted that the above observations on Figure 2 were supported by statistical significance: both augmented feedback and visual noise conditions influenced tracking accuracy. Further, the significance of blocks in Table 1 indicates the presence of skill acquisition for groups over the last six blocks of training. In the analysis, Ss within groups served as the error term for between-groups tests, while blocks × Ss within groups was used to test the within-groups effects and interactions.

Transfer

Transfer to the no-augmented-feedback condition occurred on block 11 for groups E_o and E_n. It was predicted (see above) that only group E_n would exhibit

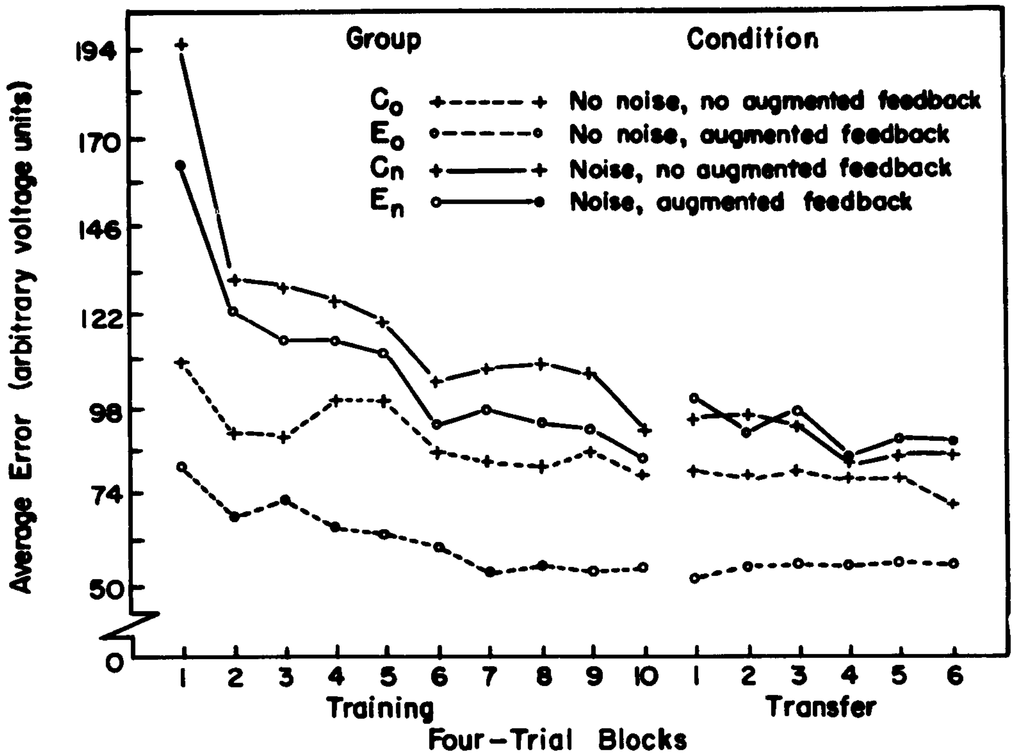

Figure 2. Training and Transfer as a Function of Augmented Feedback and Visual Noise.

Table 1

Results of the Analysis of Variance on Blocks 5-10 for All Groups (Voltage Units)

Source	df	MS	F	p
Between Groups				
Augmented Feedback (A)	1	542,159	6.06	.025
Target Noise (T)	1	1,284,218	14.40	.001
A × T	1	145,198	1.62	ns
Error (Ss within Groups)	56	84,489		
Within Groups				
Blocks (B)	5	47,018	19.10	.001
B × A	5	2,120	0.86	ns
B × T	5	4,928	2.00	ns
B × T × A	5	2,219	0.90	ns
Error (B × Ss within Groups)	280	2,464		

performance deterioration during transfer, and examination of Figure 2 shows that this prediction was supported completely by the data: upon transfer group E_n performance deteriorated abruptly to the same level attained by the appropriate control group, group C_n. (Both groups E_n and C_n continued to experience visual noise during transfer, of course.) However, group E_o shows no change upon transfer.

In order to evaluate these observations, a t test was performed on the difference in performance between block 10 and block 11 for each group. Only the t test for group E_n was statistically significant at $p < .05$ ($t = 3.50$, df = 14).

DISCUSSION

The above results provide unequivocal support for the hypothesis that performance following transfer to no augmented feedback will deteriorate if *S* has attempted to use such feedback in place of fundamental feedback information during the training period. Augmented feedback emerges, then, as a most useful training variable, but one that can be misused: care must be exercised by the instructor to avoid the possibility that *S* will substitute augmented for fundamental feedback. It is apparent that *S* will so misuse augmented feedback if the fundamental feedback signals are degraded.

One solution, then, is to assure that the fundamental feedback cues are clearly perceptible in the training task. However, while this would decrease the possibility that *S* will misuse augmented feedback, it may be argued that in a training task fundamental feedback cues should be of the same characteristics as those in the operational task for which training is being undertaken, and if those cues are obscure or noisy, the training task should represent the cues with fidelity (and thus be obscure or noisy). Previous research on training under conditions of visual noise does not support this latter contention: Briggs, Fitts, and Bahrick (ref. 6) found no differential effects of training under noise or under no-noise conditions when *S* transferred either to a noise-free or to a noisy display. The argument, then, is strengthened that noise-free and clearly perceptible displays of fundamental feedback should be employed in vehicular control training tasks and that augmented feedback will be a useful training technique for shaping behavior without detrimental consequences following transfer to a no-augmented-feedback (operational) situation.

At a theoretical level, it follows from the above that augmented feedback can exert a relatively permanent effect on performance, which suggests that if appropriately used, augmented feedback influences learning. However, if misused, as by group E_n, the effect of augmented feedback is on performance only, not necessarily on learning.

SUMMARY

Four groups of *Ss* received 64 30-second trials of tracking experience. Groups E_n and E_o experienced augmented feedback, in the form of auditory clicks at the rate of 2 per second when on target, for 40 training trials. They then received 24 trials without augmented feedback. Groups C_n and C_o tracked the entire 64 trials without augmented feedback. Groups E_o and C_o tracked a noise-

free display while groups E_n and C_n experienced random perturbations of the reference element of the tracking display (visual noise).

It was predicted that the performance of group E_n would deteriorate upon transfer to the no-augmented-feedback condition, while that of group E_o would remain superior to its control group, group C_o. The results confirmed this prediction: upon transfer group E_n deteriorated in tracking accuracy to the previously inferior level attained by group C_n, whereas group E_o showed no performance deterioration.

These results were interpreted to mean that S will treat augmented feedback as if it were fundamental feedback when these latter cues are degraded. This amounts to a misuse of augmented feedback in that it is no longer supplemental but fundamental to accurate performance. Thus, in transfer to an operational (no augmented feedback) task, S will deteriorate in performance, thereby clearly indicating that augmented feedback was a crutch during training and that it exerted no lasting benefit on performance.

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